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Ambiguity in the Land Use Component of Mitigation Contributions Toward the Paris Agreement Goals

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Key Points:
- There is a wide variation in how countries include the land sector in their national mitigation contributions under the Paris Agreement
- Most countries provide an ambiguous land use mitigation target, causing ~3 GtCO2/year uncertainty in global land use emissions in 2030
- To reduce this uncertainty, countries could clarify their land sector mitigation plans by providing clear and distinct land use targets

Supporting Information:
- Supporting Information S1
- Data Set S1

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Abstract Land use, land use change, and forestry (LULUCF) activities, including deforestation and forest restoration, will play an important role in addressing climate change. Countries have stated their contributions to reducing emissions and enhancing sinks in their Nationally Determined Contributions (NDCs); in 2023, the Global Stocktake will assess the collective impact of these NDCs. Clarity in the contribution of LULUCF to NDC targets is necessary to prevent high LULUCF uncertainties from undermining the strength and clarity of mitigation in other sectors. We assess and categorize all 167 NDCs and find wide variation in how they incorporate LULUCF; many lack the clear information necessary to understand what land-based mitigation is anticipated. The land sector is included in 121 NDCs, but only 11 provide a LULUCF target that can be fully quantified using information presented or referenced in the NDC. By developing alternative scenarios from a subset of 62 NDCs (89 countries), we estimate that ambiguity in LULUCF contributions causes an uncertainty range in the anticipated LULUCF sink in 2030 of magnitude 2.9 GtCO2eq/year—larger in size than our best estimate for the LULUCF sink of −2 GtCO2eq/year. Clearer communication of data sources and assumptions underlying the contribution of land use to mitigation efforts is therefore important for ensuring a robust Global Stocktake and ambitious emissions reductions. We find that guidance under the Paris Agreement may improve the clarity of future NDCs but is not sufficient to eliminate ambiguities. We therefore recommend that LULUCF targets should be presented and accounted for separately from other sectors.

Plain Language Summary Land-based activities, including reducing deforestation and planting forests, play an important role in addressing climate change. Under the Paris Agreement, 195 countries agreed to produce national climate change action plans for reducing their emissions. Many of these plans already include land-based activities, but there is currently no common rule set for how to do so in a scientifically robust way. Our study shows that most national climate action plans are ambiguous in how land-based activities will contribute to reducing emissions. This makes it difficult to track the role of land-based activities in global efforts to address climate change and leaves the door open for countries to use uncertain land-based mitigation to offset emissions from burning fossil fuels. We estimate that this ambiguity causes an uncertainty of ~3 GtCO2/year in 2030; this is larger than our estimate of the total human-made land use sink in 2030 (-2 GtCO2/year). Recently, countries agreed a set of guidance for how to describe their climate change action plans. This guidance will help to reduce some ambiguity in the role of land-based mitigation, but it is not sufficient to eliminate ambiguity. We recommend that countries should keep their land-based mitigation plans separate from targets in other sectors.

1. Introduction

The Paris Agreement (PA) strengthens the global response to climate change with a long-term temperature goal of holding the increase in global average temperature to well below 2 °C and pursuing efforts to limit warming to 1.5 °C. To do this, Parties aim to collectively achieve a balance between emissions by sources and removals by sinks in the second half of this century (Articles 2 and 4, PA, UNFCCC (2015)), which will require rapid and far-reaching action in all sectors (IPCC, 2018). The agreement specifically calls on Parties to "conserve and enhance" sinks and reservoirs of greenhouse gases (GHGs; Article 5), pointing toward the role that land-based mitigation will play in contributing to global mitigation.

Parties have stated their intended contributions to climate change mitigation in their Nationally Determined Contributions (NDCs), but, collectively, these contributions are insufficient to meet the goals of the PA (Admiraal et al., 2015; Rogelj et al., 2016; UNEP, 2015; UNFCCC, 2016). Consequently, at COP21 in 2015 Parties agreed that NDCs should progress over time (Article 4.3, PA), that progress toward the

agreement's goals should be tracked, and that the pace of progress should be evaluated during 5-yearly Global Stocktakes (Article 14). This tracking and stocktaking architecture—the so-called "ratcheting-up mechanism"—seeks to enhance the NDCs over time to bring them in line with the 1.5 °C warming limit. However, challenges in estimating the globally aggregated mitigation effect of NDCs are already apparent (Benveniste et al., 2018; Rogelj et al., 2017).

A particularly challenging component is the evaluation of how land-based mitigation will contribute to overall efforts in 2030. Uncertainty in the contribution of land use, land use change, and forestry (LULUCF) activities to mitigation is substantial for a number of reasons: LULUCF data uncertainties are high (Roman-Cuesta et al., 2016); land can act as a sink as well as a source; and the ambiguity in how Parties address LULUCF mitigation adds to uncertainty over how the NDCs will be met (Forsell et al., 2016; Grassi et al., 2017). Such high uncertainties may undermine the credibility of the LULUCF contribution to overall mitigation targets; as noted by Mackey et al. (2013), the reduction or prevention of LULUCF emissions cannot meaningfully counteract the effects of continuing emissions from others sources. Nevertheless, the PA encourages Parties to set NDCs that are economy-wide, meaning that all sectors, including LULUCF, are covered. There is precedent from the Kyoto Protocol (KP) for land-based mitigation to be used to offset emissions from fossil fuels and industry (Schlamadinger et al., 2007). If, under the PA, ambiguous and uncertain land-based mitigation is used to offset emissions in a similar manner, our ability to assess mitigation targets in other sectors will be compromised, and efforts to achieve the rapid phase out of fossil fuels required for the PA 1.5 °C warming limit could be jeopardized.

In the context of the Global Stocktake, there are two different time frames for tracking progress: ex post (i.e., monitoring progress to-date with historical emissions data) and ex ante (i.e., assessing anticipated progress by comparing NDC-based projections against long-term goals). Uncertainty in ex post tracking comes primarily from historical emissions data uncertainty, driven by measurement uncertainties and definitional uncertainties, both of which are substantial for LULUCF data (Grassi et al., 2018; Pongratz et al., 2014; Roman-Cuesta et al., 2016; Tubiello et al., 2015). Ex ante tracking faces additional uncertainties caused by ambiguity over how to translate NDCs into absolute emissions, uncertainties in how recent anthropogenic emissions and removals will be counted toward NDCs (using so-called "accounting rules"; Iversen et al., 2014), and uncertainties over whether and how a Party will achieve its NDC. Previous work has considered some of these ex ante uncertainties as they apply to LULUCF by estimating the impacts of unclear LULUCF targets for a subset of NDCs (Benveniste et al., 2018; Forsell et al., 2016) and the influence of accounting rules (Grassi et al., 2017) on anticipated levels of land-based mitigation under the NDCs. These uncertainties are sufficiently large that it is unclear whether LULUCF activities will form a net source or a net sink in 2030.

Reducing LULUCF uncertainties is challenging; for example, more accurate estimates of land-based emissions require improvements in technology, methods, and institutional arrangements (Ciais et al., 2014; Romijn et al., 2018). However, NDCs and policies can be formulated in a way that minimizes the impact of these uncertainties on overall mitigation efforts and ensures effective land-based mitigation action. Until now, the extent to which NDCs achieve this clarity has not been addressed.

In this paper, we therefore undertake a comprehensive examination of how LULUCF is treated in all NDCs submitted by January 2019 in order to (i) assess how LULUCF mitigation is currently treated in the NDCs and (ii) estimate the quantitative effect of ambiguity in LULUCF contributions. We start by developing a categorization framework for the NDCs that outlines the various approaches used by Parties for including LULUCF in their NDCs and the degrees to which LULUCF contributions can be quantified. By considering all NDCs, we capture the full spectrum of approaches taken; hence, this framework can be used in the future to compare NDCs and to monitor how LULUCF treatment evolves over time. We then estimate the likely magnitudes of emissions and removals in 2030 covered by each category of LULUCF treatment to evaluate the contribution of ambiguity in LULUCF contributions to uncertainty in the impact of NDCs on 2030 emissions.

Under the PA, NDCs should be formulated to facilitate "clarity, transparency, and understanding," and Parties should account for emissions/removals in a way that promotes "transparency, accuracy, completeness, comparability, and consistency," known as the "TACCC" principles. Further guidance on how Parties should formulate and account for their NDCs consistently with these criteria was agreed in 2018 at COP24 in Poland, when the PA "rule-book" was finalized (UNFCCC, 2018b). We therefore conclude by

using our categorization framework and assessment to examine the strengths and shortfalls of the PA rulebook in terms of reducing ambiguity and uncertainty and identify priorities for how Parties can improve the clarity of their NDCs.

2. Materials and Methods

Our analysis comprises three parts: First, a categorization framework is developed for understanding the approaches used for LULUCF in the current NDCs; second, quantitative estimates of emissions and removals corresponding to a subset of NDCs allow us to evaluate which categories of LULUCF approach cover the most LULUCF emissions and removals and to estimate the scale of uncertainty caused by ambiguous LULUCF treatment; and finally, we assess different elements of LULUCF treatment in the NDCs against the principles and guidance of the PA and consider how the new rule-book may affect the degree of ambiguity in LULUCF treatment.

Our categorization includes all 167 NDCs received as of January 2019, including the "intended" NDCs of those Parties that had not yet ratified the PA as of that date. Our subsequent analysis of how LULUCF contributions translate into emissions and removals then focuses on those countries with the most substantial LULUCF emissions and removals, excluding only countries for which LULUCF emissions and removals are very low (Figure S1 in the supporting information). A subset of 62 Parties (covering 89 countries) was selected to ensure maximum coverage of LULUCF emissions/removals, while also including Parties to the KP and countries with high economy-wide emissions whose emissions profiles include a significant contribution from LULUCF (see Supporting Information S1 for further detail).

We use the category LULUCF, as used by the UNFCCC and IPCC, which encompasses human activities that impact terrestrial sinks and differs from biophysical land cover change. LULUCF is associated with higher data uncertainties than agriculture; hence, agriculture is excluded from our study (see Hönle et al., 2018, for an analysis of agriculture in the NDCs). Recent IPCC guidelines have introduced the AFOLU (agriculture, forestry, and land use) category. However, many countries have explicitly referred to LULUCF in their NDCs, with agriculture a separate category, and countries vary in their uses of AFOLU/LULUCF in their national reports to the UNFCCC. Such differences in emissions classifications and definitions present a challenge for understanding and comparing NDCs.

2.1. Categorization of LULUCF Treatment

We categorize all 167 NDCs, covering 194 countries (the EU's NDC covers 28 countries), by the type of mitigation contribution set for the LULUCF sector, both in terms of the implied accounting rules and the degree to which the contribution can be quantified. This comprehensive treatment enables us to identify (1) the types of targets that will need to be aggregated as part of the first Global Stocktake; (2) convergent and divergent elements in how countries treat land-based mitigation; and (3) the risk of uncertain LULUCF activities being used to offset fossil fuel emissions.

It is relatively straightforward to group NDCs by the overall NDC type: 28 present an absolute reduction relative to a reference year emissions level (henceforth referred to as "absolute"), 79 present a reduction relative to a business-as-usual emissions trajectory ("BAU"), 12 present an emissions intensity target (either in terms of emissions per capita or emissions per unit of GDP; "intensity"), and 45 present a contribution based on a series of policies and measures and/or metrics other than GHG emissions ("other").

NDCs are then divided according to whether or not they include LULUCF and, for those that do, we further categorize the NDCs in terms of (1) how LULUCF is integrated into the headline target of the NDC and (2) whether the LULUCF contribution can be quantified. These two elements are important, as they determine the extent to which we can understand the mitigation contribution of LULUCF and its interaction with other sectors.

Looking first at *how* LULUCF is incorporated into the NDC ("LULUCF treatment"), we note whether there is a separate LULUCF target or whether LULUCF is incorporated with other sectors as an "integrated target," either with or without a distinct land use component. Under an integrated target, it is more difficult to anticipate whether mitigation occurs through LULUCF activities or elsewhere, for example, in the energy sector. The magnitude of this uncertainty depends on the accounting rules chosen, so for NDCs with an integrated target it is also important to consider which accounting methods are used. According to the current

Table 1
Categories of LULUCF Treatment, Showing How They Are Differentiated by the Nature of the Target and the Use of Accounting Rules

LULUCF treatment category		Number of NDCs	LULUCF included?	Distinct LULUCF target?	LULUCF integrated with other sectors?	Accounting rules (if LULUCF is integrated)			Label
						Net-net accounting	KP accounting	Not specified/ undecided	
Separate		27	✓	✓					"Separate"
Integrated distinct	Net-net	1	✓	✓	✓	✓			"Integrated, distinct LU – accounting specified"
	KP rules	1	✓	✓	✓		✓		
	Accounting TBD	0	✓	✓	✓			✓	
	Unclear	17	✓	✓	?			?	"Integrated, distinct LU – unclear accounting"
Integrated	Net-net	3	✓		✓	✓			"Integrated, no distinct LU, accounting specified"
	KP rules	2	✓		✓		✓		
	Accounting TBD	6	✓		✓			✓	
	Unclear	46	✓		✓			?	"Integrated, no distinct LU, unclear accounting"
Measures-based target		18	✓						"Measures"
LULUCF inclusion to be determined		7	?	?	?			?	"Inclusion TBD"
LULUCF not included		39							"LU not included"

Note. LULUCF = land use, land use change, and forestry; NDC = nationally determined contribution. A "?" indicates ambiguity in whether a feature applies. Note that not all categories of treatment are used in the current set of NDCs.

NDCs, some Parties intend to account for LULUCF emissions and removals in the same way as all other emissions/removals (known as "net-net" accounting); some opt to use a variant of KP accounting rules; some will set accounting rules at a later date, for example, following adoption of the PA rule-book ("accounting TBD"); and the rest do not mention any accounting rules ("unclear").

We identify 10 approaches (Table 1) that are differentiated by (1) whether or not LULUCF is included, (2) the degree to which LULUCF is separated from other sectors, and (3) whether specific accounting rules are provided. Very few Parties have specified exactly how LULUCF will be treated or whether LULUCF accounting will be used to offset emissions in other sectors, so for many countries it was necessary to infer the LULUCF approach from other information included in the NDC. For example, if a single target is provided and the NDC lists LULUCF as one of the sectors covered, we assume that LULUCF contributes to the headline target. Our understanding of NDC targets relies on information submitted by countries to the UNFCCC, primarily in their NDCs. Some Parties, for example, the EU, have domestic legislation that supports the NDC, but we do not include this, as it is not clear how such legislation is bound to the NDC and whether such information will be available to the Global Stocktake.

The degree to which LULUCF contributions can be quantified also varies widely between NDCs. A number of NDCs include quantitative LULUCF targets, either for LULUCF emissions/removals or for an alternative metric, such as forested land area or deforestation rate. However, only some of these are fully quantifiable in terms of the level of emissions/removals anticipated for 2030. In many cases, the NDC is only partially quantifiable (e.g., the NDC has a quantitative target but is missing the data necessary to calculate the target, or the quantitative target cannot be translated into an emissions level without further calculations). NDCs that do not provide a quantitative LULUCF component either describe LULUCF measures and activities or do not specify how LULUCF mitigation contributes to the headline target. We therefore categorize the NDCs according to whether quantitative information is available, and the degree to which LULUCF targets can be quantified (Table 2).

Finally, we survey the NDCs for mentions of other approaches relevant to LULUCF, such as REDD+, harvested wood products, and natural disturbances (see sections S9 to S11 and Tables S12 to S14).

Table 2
Description of Classifications of How Quantifiable Different NDCs Are, Showing Which Classifications Include Quantitative Targets

Classification	Description	Quantitative target?	Quantifiable emissions target?
Emissions based, quantifiable	Quantitative LULUCF emissions/removals target that can be quantified	Yes	Yes
Emissions based, not fully quantifiable	Quantitative LULUCF emissions/removals target that cannot be quantified due to lack of information	Yes	Partially
Emissions & non-emissions based	Quantitative targets based on emissions and non-emissions metric (e.g. a deforestation target accompanied by estimated emissions reductions), but a total LULUCF emissions target cannot be quantified due to lack of information.	Yes	No
Non-emissions based	Quantitative target based on a non-emissions metric (e.g. forest area, deforestation rate)	Yes	No
Not quantitative	Qualitative target (e.g. policies and measures) or no explicit LULUCF target	No	No

Note. LULUCF = land use, land use change, and forestry; NDC = nationally determined contribution.

2.1.1. Methods for Estimating NDC Targets

We next estimate the total LULUCF and non-LULUCF emissions in 2030 implied by 62 selected NDCs. For comparison, we also estimate the average net LULUCF emissions over the period 2004–2010. This analysis is designed to fulfil two purposes: first, to determine "best estimates" for LULUCF carbon fluxes in 2030 that we can use to evaluate how emissions/removals are spread across different categories of LULUCF treatment and, second, to explore the quantitative effect of ambiguity in LULUCF treatment. As far as possible, information provided by Parties is used to calculate "best estimates," and this information is complemented by a range of theoretically reasonable LULUCF scenarios. Our methods, described below, depend on the nature of the NDC, the data available, and whether LULUCF emissions are a net source or sink in the country (see Table S6 and Texts S2 to S5 for more detail).

Where an NDC includes projections of LULUCF and non-LULUCF emissions in 2030, there is no ambiguity, and our 2030 estimate is based on information from within the NDC.

Where a quantitative headline target is provided but detail on the LULUCF contribution is lacking such that a single estimate for LULUCF cannot be made, we derive up to three scenarios for each country, one of which forms our "best estimate." Using different scenarios enables us to identify a range of possible values for total net LULUCF emissions in 2030 for NDCs that are ambiguous in their LULUCF contribution. While the assumptions underlying our scenarios are not necessarily realistic for all Parties, they are the best assumptions we can make given the lack of counterfactual data, allowing us to map out the full range of reasonable outcomes. This approach goes beyond previous studies that have only assumed a continuation of historical emissions in cases where no other data are available.

Some countries provide a projection of LULUCF emissions/removals in their national reports submitted under the UNFCCC (see sections 2.3.2 and S4 and Table S7), and we use such projections for at least one of the scenarios. If multiple projections are available, we base the "best estimate" scenario on the projection that, in our judgment, is best aligned with the country's NDC. However, projections may be changed in the future and do not represent an agreed strategy; hence, they are not necessarily consistent with the NDCs. We therefore base at least one scenario on a continuation of average historical emissions/removals. We exclude any projections that are clearly not aligned with the NDC, for example, if the underlying historical data are inconsistent or if projections suggest a growth in LULUCF emissions while the NDC implies a reduction. The range in emissions/removals across the scenarios is an indicator of uncertainty in LULUCF mitigation caused by a lack of clarity over which data sources are compatible with the NDC.

Many Parties do not have any projections available in national reports; for these NDCs we construct scenarios based on historical data and potential future trends. Our methods differ according to whether a Party's net LULUCF contribution is positive (net emissions) or negative (net removals), as this affects how LULUCF emissions and removals are likely to change in the future.

If a country has net LULUCF emissions, the first scenario assumes the most ambitious action in the land sector, the second assumes similar efforts across all sectors, and the third assumes a continuation of the status quo in the LULUCF sector.

1. Net zero LULUCF emissions by 2030: LULUCF emissions go to zero by 2030. This assumes that the New York Declaration on Forests (United Nations, 2014) is successful—that is, that natural forest loss is ended by 2030—and requires that other land-based activities do not result in net emissions.
2. Constant LULUCF share (best estimate case): LULUCF emissions fall at the same rate as total emissions, so the proportion of total emissions coming from LULUCF in 2030 remains constant at recent historical levels, calculated as the average for the period 2004–2014.
3. Constant absolute LULUCF emissions: LULUCF emissions remain at recent historical levels, calculated as the average for the period 2004–2014.

The range in emissions/removals across the scenarios represents the range in carbon fluxes that results from two different policy outcome end-members: either the successful implementation of the New York declaration on forests and the reduction of land-based emissions to zero or a continuation of historical emissions levels.

These scenarios do not work well for countries with net LULUCF removals because the first (net zero LULUCF emissions) is not appropriate for countries with a net LULUCF sink and the second (constant LULUCF share) is unlikely to be realistic under a climate mitigation scenario. Two countries in our analysis (Serbia and South Africa) are net sinks with no available LULUCF projections, so we make only one estimate for each by assuming that removals remain at historical levels, and we cannot estimate the effect of ambiguity.

For a small number of NDCs, different levels of information provision mean that we adjust our methods. Some NDCs provide quantitative LULUCF targets that need additional data to be calculated in terms of emissions/removals. If such data are readily available (e.g., IPCC guidelines or national data), we use this to calculate a LULUCF target, and if there is an element of ambiguity in how the target is set (e.g., an uncertain baseline), we make calculations that span the possible range of targets (see Table S8). This is the case for China, India, Chile, and Cambodia. Conversely, 12 NDCs included in our analysis do not provide any quantitative information on either the level of LULUCF mitigation or the economy-wide mitigation target and instead set out a series of policies and measures or specific energy sector targets. For these NDCs we set 2030 LULUCF net emissions at average historical levels.

2.1.2. Data Sources

Historical emissions are taken from national greenhouse gas inventories and national reports under the UNFCCC (UNFCCC, 2018c) or the NDCs (accessed January 2019). If none of these are available (16 out of the 62 countries, covering ~40% of net emissions and ~1% of net removals), we use the freely available global data set from the "Emissions – Land use" domain of FAOSTAT (FAO, 2017) and PRIMAP-hist (Gütschow et al., 2016, 2018; see section S2, Tables S5 and S7, and Figure S2). FAOSTAT emissions data are not directly comparable with UNFCCC data, largely because of different definitions and data coverage (Tubiello et al., 2015), but they are calculated using IPCC methodologies and country-reported data.

For LULUCF projections, our highest priority data source is the NDCs. The majority of NDC targets are for 2030; hence, we extrapolate any targets for 2025 to 2030 to enable comparison. Sections S3 to S9 provide further detail on methods. Our analysis looks at the most stringent targets in the NDCs, but results based on unconditional targets only are in Figure S8. For NDCs that do not include any LULUCF projections, we next prioritize national reports under the UNFCCC (National Communications [NCs], Biennial Reports [BRs], and Biennial Update Reports [BURs]), although these do not necessarily correspond to emissions targets (see section S4). We use only reports submitted to the UNFCCC, as these will also be available for the UNFCCC Secretariat to use for the Global Stocktake. In some cases, the choice of data source has a considerable impact on our best estimate for 2030. For example, our best estimate for the USA uses the "high sequestration" scenario from the second BUR (U.S. Department of State, 2016), which includes a LULUCF sink that is over 300 MtCO2eq larger than the "low sequestration" scenario used for our third scenario.

2.2. Assessing NDCs Against the PA's Principles and Guidance

We assess whether the LULUCF approaches identified in our categorization are compatible with the PA rule-book to identify the potential impact of the rule-book on how NDCs are formulated. We also look at a number of LULUCF-specific elements covered by the rule-book (either explicitly or implicitly) to assess the adequacy of the rule-book for ensuring the PA's requirements for how NDCs should be formulated.

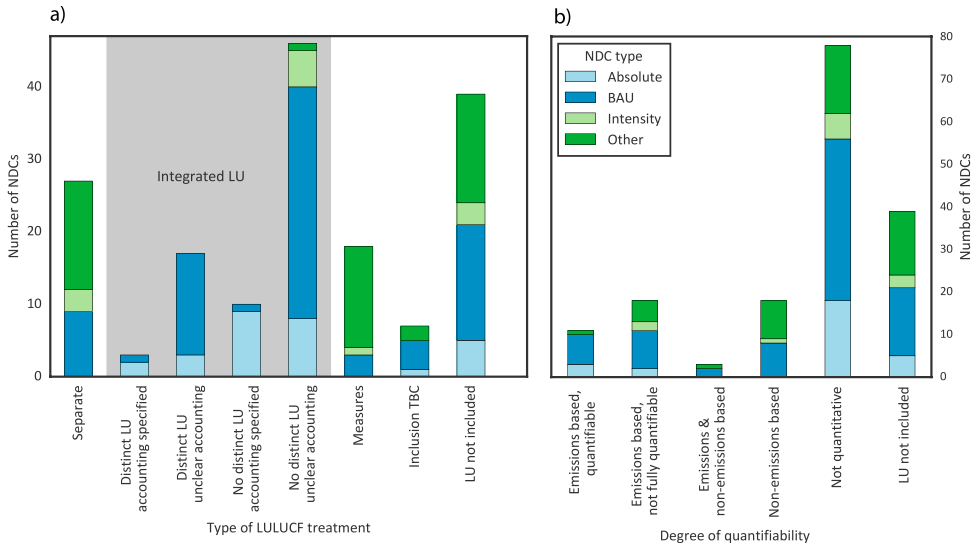

Figure 1. Number of NDCs categorized by (a) LULUCF treatment type and (b) degree to which LULUCF targets can be quantified. Descriptions of labels in (a) and (b) are in Tables 1 and 2, respectively. Colors show the overall NDC type. LULUCF = land use, land use change, and forestry; NDC = nationally determined contribution; BAU = business-as-usual emissions trajectory.

This work draws from documents and decisions from the UNFCCC and IPCC, as well as experiences from the UNFCCC negotiations since 2015.

3. Results

We use the categorization framework described in section 2 to show the variation in how the current NDCs incorporate LULUCF, and the degree to which LULUCF contributions are quantifiable. We then use our estimates of LULUCF emissions/removals in 2030 to show which types of LULUCF treatment are the most significant in terms of emissions/removals covered and estimate the impact of ambiguity in LULUCF contributions.

3.1. Categorization

One-hundred sixty-seven NDCs were categorized according to the scheme described in section 2—Tables S1–S3 show the results of this categorization, covering NDCs with quantitative LULUCF targets, unquantified LULUCF targets, and no distinct LULUCF targets, respectively.

The categorization shows wide variation in how the NDCs incorporate LULUCF (Figure 1), but three types of LULUCF treatment dominate: “integrated, no distinct LU target, unclear accounting” (46); “separate” (27); and “LU not included” (39; Table S4). Only 13 NDCs anticipate the use of accounting rules for their integrated targets, and 18 NDCs provide measures and policies for LULUCF mitigation.

Most NDCs that include LULUCF do not provide any kind of quantitative LULUCF target (78 NDCs; Figure 1b). Of those that do include a quantitative LULUCF target (50 NDCs), only 11 can be fully quantified in terms of LULUCF emissions/removals, while 18 provide a target based on emissions/removals that is not fully quantifiable (e.g., a reduction is provided without a reference level; see Text S5 and Table S8), 18 provide a target based on an alternative metric (e.g., forest area and deforestation rate), and 3 combine the latter two.

A third of all NDCs (59 in total) provide only an integrated target with no quantitative LULUCF contribution. Such treatment results in a high degree of ambiguity over what portion of economy-wide mitigation is expected from action in LULUCF, yet it is the most common type of LULUCF treatment for absolute, BAU, and intensity NDCs.

The categorization was rarely straightforward. Some countries do not specify whether or not the LULUCF sector is included but state that the NDC covers all emissions, so coverage of LULUCF removals is only implied (e.g., Serbia). Many developing countries list LULUCF as one of the sectors covered but do not

describe how it will be included, and for some it is unclear whether reductions are against a baseline scenario with or without LULUCF emissions (e.g., Russia, Peru). For NDCs with multiple targets it is not always clear how LULUCF targets interact with headline targets (e.g., China and India). We have endeavored to capture this lack of clarity in our categorization, but there may be some instances where our interpretations differ from those of others.

3.2. Emissions/Removals Coverage of Different Types of LULUCF Contribution

We next use our best estimates for 2030 LULUCF emissions/removals to identify which LULUCF approaches cover the most emissions/removals. Here we use "emissions" to mean the sum of best estimate LULUCF emissions in 2030 from all countries with net LULUCF emissions and "removals" to mean the sum of best estimate LULUCF removals in 2030 from all countries with net removals, respectively.

Poorly quantified LULUCF contributions dominate both emissions and removals: 45% of best estimate LULUCF emissions (910 MtCO2eq), and over two thirds of best estimate LULUCF removals (−2,800 MtCO2eq) are associated with NDCs that lack any quantitative LULUCF target (Figures 2a and 2b). Most LULUCF emissions in this nonquantitative category (60% of emissions, or ~1,200 MtCO2eq) are covered by BAU NDCs that integrate LULUCF under a headline mitigation target with no distinct LULUCF target and no description of LULUCF accounting rules. Nigeria and Tanzania have the largest best-estimate LULUCF emissions in this category, at over ~150 MtCO2eq/year each. The majority of removals in the nonquantitative category (47%; −2,000 MtCO2eq/yr) are covered by an NDC that offers no distinct LULUCF target but does specify some form of accounting rules. The United States, which treats LULUCF as any other sector (net-net accounting), dominates this category; many other countries (21% of removals) have not yet determined their accounting rules, and only a small proportion (<1% removals) specify KP accounting rules.

Very few best estimate emissions and removals are covered by NDCs with a fully quantifiable LULUCF emissions/removals target: only 6% (~120 MtCO2) of emissions and 12% (approximately −500 MtCO2) of removals. Indonesia contributes the most emissions to this category, providing not only a quantifiable LULUCF target but also the assumptions underlying it. For removals, Mali and Madagascar are the most significant sinks with quantifiable targets.

About 500 MtCO2eq of emissions (27%) are covered by NDCs with a distinct, quantitative LULUCF target that is integrated under the headline target; these are all covered by targets that are not fully quantifiable because, for example, they do not include their complete land use sector, or baseline data are not provided (see Table S8).

Separate LULUCF targets cover only about a quarter of removals (~1,100 MtCO2eq; 27%) and emissions (~500 MtCO2eq; 23%). Madagascar, Central African Republic, and India are the largest net sinks in this category (we assume that the land sector target for India is independent from the headline intensity target). These countries all provide a LULUCF emissions/removals target that is at least partially quantifiable. Conversely, all net emitters in this category do not provide an emissions target. For example, Sudan, the largest emitter in this category, has a target for reforestation/afforestation to reach 25% of forest cover by 2030.

Other categories of LULUCF treatment cover small shares of best estimate emissions and removals, in total covering 13% of emissions and 10% of removals (Figure 2). The 39 NDCs that do not include LULUCF make up 3% of emissions and 2% of removals.

Figure 2c shows that BAU NDCs cover three quarters of LULUCF emissions anticipated in 2030, but only 26% of estimated removals. There is a notable skew in coverage of removals toward absolute NDCs with integrated targets and specified accounting rules, which likely results from the prevalence of net sinks among Annex I countries (Figures 2c and S9). One reason for this may be the legacy effects of historical deforestation, with regeneration now leading to CO2 absorption, but the approach used by developed countries to report emissions and removals likely also plays a role (see section S6).

3.3. Quantitative Ambiguity Assessment

For this analysis, insufficient LULUCF data are provided directly in most current NDCs to estimate LULUCF contributions without looking to other sources. The majority of the 62 NDCs analyzed (43 NDCs covering 69% of emissions and 71% of removals) do not provide LULUCF data, either in the form

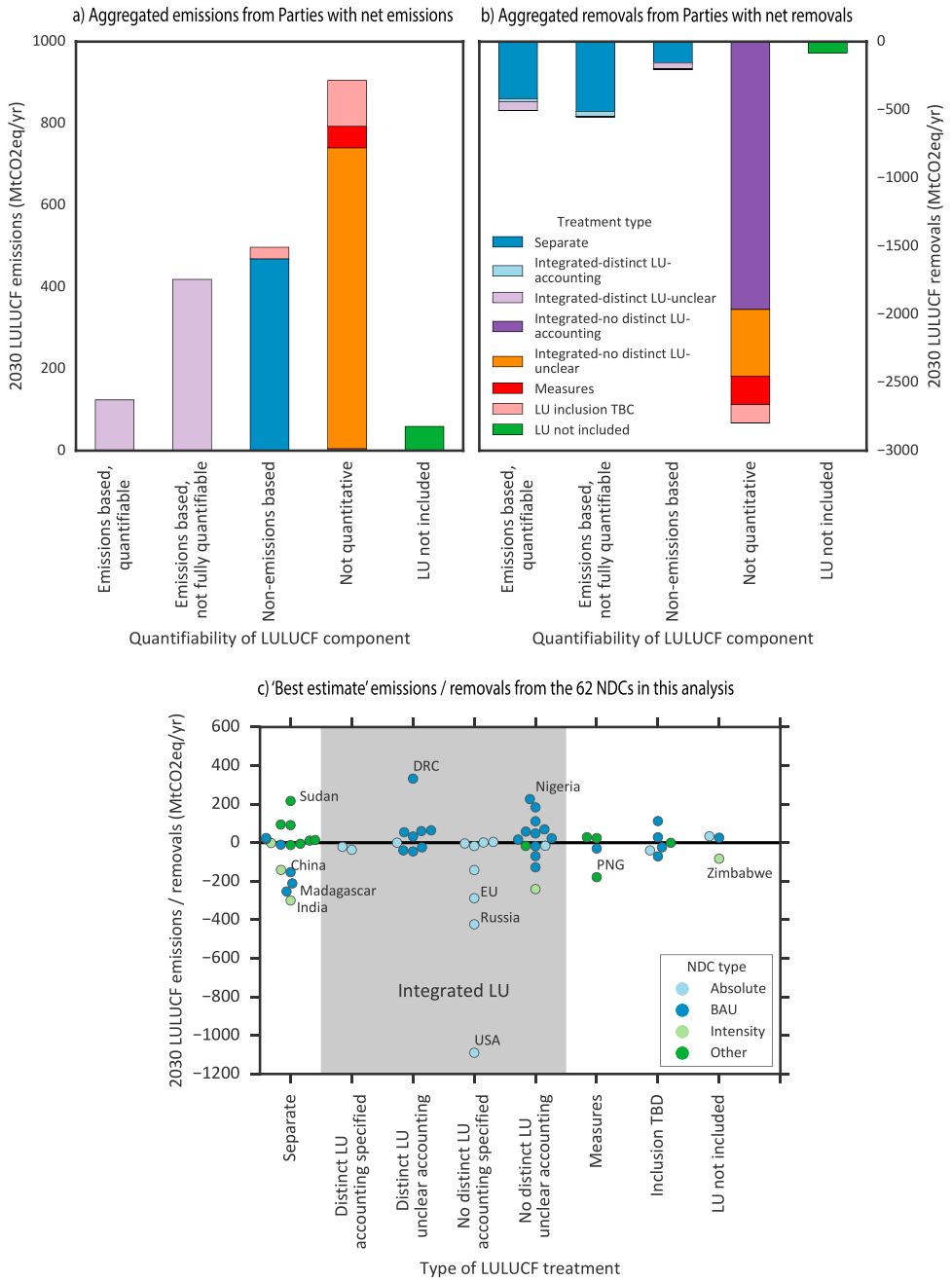

Figure 2. Best estimate aggregate 2030 emissions (a) and removals (b) for the countries included in the quantitative analysis, by the degree to which LULUCF contributions can be quantified (most quantifiable on the left), and by type of contribution. (c) Best estimate net 2030 emissions /removals for each country in the quantitative analysis, by overall NDC type and LULUCF contribution type. We have labeled larger emitters/sinks and countries discussed in the text (LULUCF = land use, land use change, and forestry; NDC = nationally determined contribution; DRC = Democratic Republic of Congo; PNG = Papua New Guinea).

of a target or a BAU projection. Only 15 NDCs contain a LULUCF target that can be quantified, and a further four provide a BAU projection but no projections of target emissions (Figure S2).

When aggregated across all countries, our best estimate for 2030 net LULUCF emissions comes to −2.0 GtCO2eq/year, with a range of −0.9 to −3.7 GtCO2eq/year. Countries not covered by our quantitative analysis are included in this estimate by assuming that LULUCF emissions/removals for these countries remain at average 2004–2014 levels.

Our range in 2030 overlaps with the lower end of Grassi et al.'s (2017) estimate (−1.1 +/− 0.5 GtCO2eq/year), but not with estimates by Admiraal et al. (2015; 1.3 GtCO2eq/year) and Forsell et al. (2016; 1.8–2.5 GtCO2eq/year), both of which project a net LULUCF source in 2030. This is partly because these studies harmonized their results to FAO data, which use different land use change definitions to data submitted under the UNFCCC and therefore tend to give smaller sinks (see section S6, Figure S4, and section 3.3.1). Additionally, our estimates are based on optimistic assumptions such as the success of the New York declaration on forests. Country level variation between studies, caused by different assumptions and data sources, is described in section S7, Figure S6, and Table S9. Results for unconditional targets are provided in section S1.2.1.

For comparison with recent emissions levels, our estimate for average 2004–2014 net LULUCF emissions for all countries is 0.7 GtCOeq/year, consistent with Grassi et al.'s (2017) estimate for 2010 of 0.0 ± 1.0 GtCO2eq/year. If we only use FAO data for our historical emissions estimate, rather than nationally reported data, this yields much larger emissions for this period of 3.3 GtCO2eq/year, similar to Forsell et al.'s (2016) estimate for 2010 (~3 GtCO2eq/year), which also used FAO data.

For the 43 NDCs with no LULUCF emissions/removals data we used the methods outlined in section 2.2 to provide three alternative LULUCF scenarios for 2030 (see Figure S7 for countries with the greatest ranges across these scenarios). Aggregated across all NDCs, our minimum, best, and maximum estimates for net LULUCF emissions are −3.7, −2.0, and −0.9 GtCO2eq. The range across these scenarios (2.9 GtCO2eq) illustrates the degree of uncertainty caused by ambiguity in how LULUCF mitigation contributes to emissions reductions in these NDCs. Total LULUCF uncertainty also comprises additional types of uncertainty (see section 3.3.1 below). However, the previously unquantified magnitude of uncertainty caused by ambiguity in LULUCF mitigation indicates how such ambiguity could affect mitigation targets (including for non-LULUCF sectors) and render the comparison and aggregation of NDCs for the Global Stocktake more difficult. Furthermore, our analysis illustrates that the quantification of uncertainty caused by ambiguity is difficult and requires assumptions to be made around what future LULUCF emissions/removals could look like under the NDCs. The assessment of uncertainties in aggregations for the Global Stocktake will face similar challenges.

We identify three main sources of ambiguity in LULUCF mitigation. First, where countries have provided projections of emissions or removals independently of their NDC, we face uncertainty over whether such projections are consistent with the NDC. In quantitative terms, we estimate this uncertainty as the difference between an available projection and a continuation of historic levels. Sixteen NDCs (57% of best estimate removals) fall under this "data source ambiguity" category, with an aggregate uncertainty of 1.0 GtCO2eq. These are predominantly absolute NDCs from Annex I Parties with net removals that include LULUCF under the headline target using either net-net accounting or accounting rules that will be determined at a later date (Figures 3, S3, and S10).

Second, for those countries that do not provide a LULUCF projection either in their NDC or in other documents submitted to the UNFCCC, the degree of LULUCF mitigation is uncertain because there is insufficient data available. Twelve NDCs (57% of estimated emissions; 8% of removals) have emissions ranges due to this "insufficient data" uncertainty, most of which integrate the LULUCF sector under a headline BAU emissions target with no detail on accounting. In our analysis, the uncertainty for these NDCs corresponds in most cases to the difference between LULUCF emissions going to zero by 2030 and LULUCF emissions continuing at historic levels. This uncertainty comes to 1.0 GtCO2eq, predominantly from developing countries with net emissions (Figures 3, S3, and S10).

Finally, four NDC targets (0% of emissions and 11% of removals) were partially quantifiable but required additional data and calculations to determine LULUCF emissions/removals in 2030. Ambiguity over what reference levels and/or assumptions to use for these calculations leads to an estimated uncertainty of 0.8 GtCO2eq, mostly from China and India. Note that this range does not include data uncertainties (e.g., uncertainties arising from the use of different historical data sources). All four of these NDCs either have a partially quantifiable LULUCF target or a nonemissions target that can be converted using national data or IPCC conversion factors. Table S8 contains explanations for how targets were calculated and recommendations for improving the clarity of partially quantifiable NDCs.

Our uncertainty range of 2.9 GtCO2eq/year is larger in magnitude than total projected net LULUCF emissions in 2030 and approximately 5% of estimated total global emissions in 2030 under the NDCs (52–58

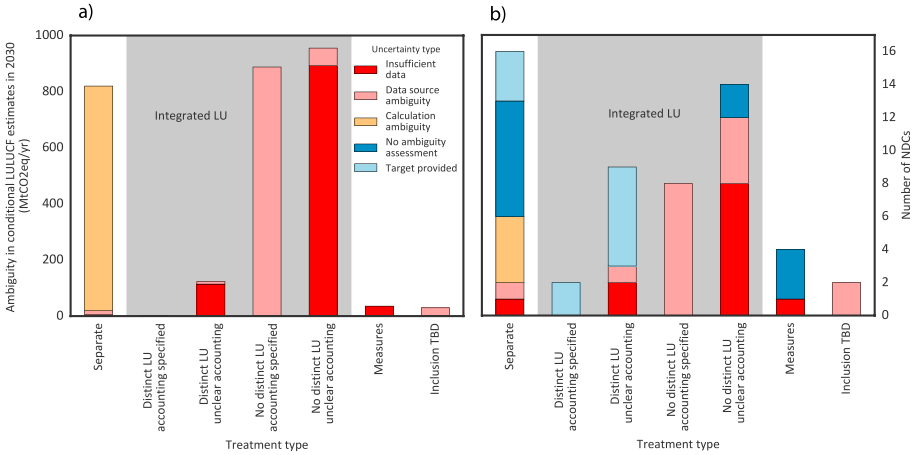

Figure 3. Ambiguity in LULUCF estimates in 2030 (a) and the number of NDCs (b) for different types of LULUCF treatment identified in our categorization framework, color-coded by the cause of ambiguity: ambiguity caused by a lack of data provided in the NDC or other national reports (red); uncertainty in the relevance of national LULUCF projections that are not included in the NDCs (blue); and ambiguity in how to quantify the LULUCF contribution, where a calculation is necessary (yellow). Some NDCs do not have ambiguity assessments here, either because the NDC as a whole (not just LULUCF) is ambiguous (dark blue) or because the NDC includes a quantifiable LULUCF target (light blue). LULUCF = land use, land use change, and forestry; NDC = nationally determined contribution.

GtCO2eq/year; IPCC, 2018). It is larger than the uncertainty over whether LULUCF mitigation targets that are conditional on, for example, financial support, will be met (0.5–0.7 GtCO2eq/year; see Text S12 and Figure S8), and similar in size to the uncertainty due to conditionality of the NDCs as a whole, identified by Rogelj et al. (2017; 1–2.7 GtCO2eq/year). Approximately two thirds of the 2.9 GtCO2eq uncertainty is associated with NDCs that integrate LULUCF under a headline target, which means that 2 GtCO2eq of uncertainty would also affect non-LULUCF emissions targets.

Not all NDCs are included in this ambiguity assessment, which only covers those NDCs that have a quantified headline target and are ambiguous in how LULUCF contributes. Of the remaining countries in our quantitative analysis, 12 (25% of emissions and 6% of removals) include LULUCF in the scope of the NDC but provide neither a quantifiable, economy-wide headline emissions target nor a national LULUCF projection; hence, ambiguity extends across all sectors. For these NDCs the NDC as a whole is uncertain, and the contribution of ambiguous LULUCF targets in this uncertainty is difficult to assess. Seven NDCs (10% of emissions and 5% of removals) do not include LULUCF in their NDC. In both latter cases, we make one estimate based on historical LULUCF emissions/removals, so the uncertainty range is zero. Only 11 of the 62 NDCs in our quantitative analysis (accounting for 8% of emissions and 13% of removals) provide sufficient information to quantify the LULUCF component, meaning that there is no uncertainty due to ambiguity in our assessment (see Figures 3 and S10).

3.3.1. Other Sources of Uncertainty

Under a full uncertainty estimate, our uncertainty range would be amplified by other uncertainties that are prevalent in the land use sector (see section S12.2 for more detail). These include the effects of different accounting rules, which are discussed elsewhere (e.g., Böttcher & Graichen, 2015; Grassi et al., 2017; Hansis et al., 2015 and UNFCCC, 2016), methodological uncertainties in how estimates of historic emissions and emissions projections or are made (Ciais et al., 2014; Krause et al., 2018; Smith et al., 2014), and uncertainties in LULUCF emission measurements, estimated at around ±50% (Gütschow et al., 2016; Le Quéré et al., 2018; Tubiello et al., 2015).

Our analysis does not consider uncertainties caused by differences in how emissions fluxes in the land sector are defined and categorized, and in the completeness of different data sets (Pongratz et al., 2014; Roman-Cuesta et al., 2016; Tubiello et al., 2015). A growing body of literature has highlighted how different methods for estimating anthropogenic sinks can lead to very different results; for example, there are clear discrepancies between country-reported LULUCF data and emissions data from land use models (Grassi et al., 2018).

Table 3
Recommendations for How the Ambiguity of Different Types of NDC Could Be Lowered by Providing Additional Information, With Example Countries From Our Quantitative Analysis That Each Recommendation Could Apply to

Recommendation	Which type of NDCs does this apply to?	Example countries from our quantitative analysis that this applies to
Provide an explicit, separate LULUCF target	NDCs with no quantified LULUCF target	Argentina, Australia, Canada, Colombia, EU, Iran, Kenya, Malaysia, Mexico, New Zealand, Nigeria, Pakistan, Paraguay, Peru, Russia, Serbia, South Africa, Switzerland, Tanzania, Turkey, Ukraine, USA, Viet Nam
Translate LULUCF target into emissions/removals and clarify how this relates to any headline target	NDCs with a LULUCF target that is not quantifiable in terms of emissions/removals	Angola, Brazil, Cambodia, Central African Republic, China, Uruguay
Provide reference indicator data (e.g. reference emissions level)	NDCs with a partially quantifiable LULUCF target	Angola, Chile, China, India, Uruguay
Clarify which activities or land types are included in the NDC	NDCs with a partially quantifiable LULUCF target	Angola, Japan
Ensure data consistency (both within the NDC and between the NDC and other national documents)	NDCs with a partially quantifiable LULUCF target	Democratic Republic of Congo, Zambia

Note. LULUCF = land use, land use change, and forestry; NDC = nationally determined contribution.

Our results have illustrated the differences between the FAO data set for LULUCF emissions/removals and country-reported data (see Text S6 and Figure S4); for example, Canada, Papua New Guinea, and Zimbabwe report a net LULUCF sink while data from the FAO shows them to be net LULUCF emissions sources. Such discrepancies are largely due to differences in how forests are defined (Federici et al., 2015), and differences are largest for projected net sinks (Figure S5). In undertaking this analysis, we also found that LULUCF data in GHG inventories can change substantially over subsequent iterations, possibly due to changing definitions, methods, coverage, and/or data sources. Such changes and discrepancies between data sets present considerable challenges for comparing or combining data sources when aggregating the NDCs.

Finally, uncertainty in whether or not an NDC will be achieved could be important for some countries, particularly those with large LULUCF fluxes and changing or conflicting policy objectives, such as Brazil and Indonesia (Brown et al., 2019).

4. Discussion

4.1. Ambiguity in the NDCs—Lessons Learned

The PA requires all Parties to provide an NDC that communicates ambitious efforts toward achieving global climate change mitigation in a way that is clear, transparent, and understandable (Article 4, UNFCCC, 2015). Parties should also seek to include all anthropogenic emissions/removals covered by their NDCs in their accounts (Article 4, UNFCCC, 2015), facilitating comparison across the NDCs and ensuring that emissions are not missed or counted more than once (in two different categories or by two different countries) when NDC efforts are aggregated. By categorizing all 167 NDCs (194 countries), we have shown that the majority of NDCs submitted to-date do not meet all of these criteria when communicating how LULUCF will contribute to their mitigation targets. Only 11 NDCs include a distinct and quantifiable LULUCF target, while 78 do not provide any quantitative information on LULUCF mitigation, of which the majority include LULUCF mitigation under a headline target without indicating the share of emissions from LULUCF activities.

Our analysis shows that ambiguous LULUCF treatment results in an uncertainty range in estimated 2030 LULUCF emissions of 2.9 GtCO2eq, which is larger in magnitude than our aggregated best estimate 2030 LULUCF net sink. About a third of this uncertainty is due to a lack of clarity over which data sources are consistent with the NDCs; ~40% comes from those NDCs that do not provide sufficient data for their LULUCF contributions to be understood; and the remainder is from NDCs that provide quantitative LULUCF targets but are ambiguous in how these should be translated into emissions reductions. All of these forms of ambiguity could be substantially reduced through a more consistent, transparent, and thorough treatment of LULUCF in the NDCs (concrete recommendations are provided in section 4.3 and Table 3).

An additional form of ambiguity illustrated by our categorization framework and also quantitatively assessed elsewhere (Grassi et al., 2017) is ambiguity in how LULUCF emissions/removals will be accounted toward a headline target. The comparatively high measurement uncertainties in LULUCF emissions/removals mean that it is important to differentiate between LULUCF mitigation and mitigation in other sectors and to be clear about how these interact. From our study, 1.9 GtCO2eq of uncertainty comes from those NDCs that include LULUCF under an umbrella economy-wide target, without providing any quantitative indication of the emissions/removals that LULUCF will contribute (Figure 3). This uncertainty could leak to other sectors, creating an uncertainty in total mitigation equivalent to more than 10% of the remaining fossil fuel CO2 emissions in 2030 that would be compatible with a limiting warming to 1.5 °C (~20 GtCO2eq; IPCC, 2018).

The variety and ambiguity in LULUCF accounting approaches may be due in part to the legacy of previous LULUCF accounting approaches. Our categorization shows clear differences in how developed and developing countries treat LULUCF: Although substantial progress has been made in breaking down the division between developed and developing countries (Mace, 2016), institutional and practical inertia play a role in maintaining some separation. Countries with KP targets are more likely to refer to the KP and/or use specific LULUCF accounting in their NDCs (see Table S14), while developing countries are more likely to anticipate a contribution from REDD+ (see section S10 and Table S13) or do not specify any LULUCF accounting rules. This may reflect administrative capacities and institutional experience: the stringent monitoring, reporting, and verification required to ensure the robustness of KP-like schemes, which allow LULUCF mitigation to offset emissions in other sectors, are costly, onerous, and complicated. Notably, at least 19 REDD+ countries do not refer to the REDD+ scheme, suggesting that action in the forest sector may be underrepresented in national contributions (Petersen & Varela, 2015) and that the formal links between the two processes are currently underdeveloped.

The vested interests of Parties that have relied on land sector removals and related accounting for the achievement of their previous mitigation targets has likely also contributed to current variation and ambiguity in LULUCF treatment. Some KP countries have indicated a shift in accounting approaches away from the KP rules (e.g., Australia, the European Union, and New Zealand), which, in some cases, may reflect a change in the sector that would make an alternative accounting approach favorable (Rocha et al., 2015; Young & Simmons, 2016).

4.2. The PA Rule-Book and Ambiguity

There was little time or political will before COP 24 to negotiate a comprehensive LULUCF rule-set for the PA rule-book; instead, most of the NDC guidance (UNFCCC, 2018b) applies to all sectors and is written in a way that is inclusive of all existing LULUCF approaches. In this section, we assess whether the rule-book adequately addresses ambiguity in LULUCF contributions, looking first at general guidance before focusing on a few LULUCF-specific accounting elements. We focus on PA guidance for NDCs, which applies for targets set in the future, but note that the PA rule-book also includes guidelines for how Parties should report ex post progress (UNFCCC, 2018a), which are discussed at the end of this section.

The PA guidance on NDCs sets out the information Parties should include in their NDCs, as appropriate for their specific mitigation target type. This includes quantifiable information on any reference indicators used (e.g., BAU projections or reference year values), data sources used for reference indicators, NDC scope, and how approaches are consistent with IPCC guidelines. This guidance should improve the transparency and clarity of NDC headline targets. Our analysis found that about 1 GtCO2eq of uncertainty results from ambiguity over which data sources are consistent with the NDCs, and a further 0.7 GtCO2eq of uncertainty is caused by a lack of reference indicator data. The requirement for Parties to quantify emissions/removals in the reference year or BAU and to disclose the data sources used for doing so may help to reduce this uncertainty. However, there are no requirements for the anticipated contribution of LULUCF to be described or quantified, so the role that land-based mitigation plays in overall targets will not necessarily become clearer. Consequently, the rule-book is likely to have a minimal effect on our estimated ~1 $GtCO_2eq$ uncertainty caused by those countries that have not provided an indication of what LULUCF mitigation will contribute to their overall targets, either in their NDCs or in other documents they have submitted to the UNFCCC.

Further guidance requires Parties to provide information on the approaches and assumptions used to estimate and account for emissions and removals when reporting progress toward their NDCs. Currently, most Parties have not specified their accounting approaches, so this guidance will improve transparency and understanding of the NDCs in this regard. However, the guidance does not indicate which accounting approaches would ensure that the PA's TACCC principles for accounting are met. The choice of net-net, gross-net, or accounting against a reference level is open, as is the choice between land-based LULUCF accounting (as used under the UNFCCC) and activity-based accounting rules (from the KP). Parties can even develop their own accounting methods if IPCC guidelines cannot be applied. Hence, Parties can choose an approach that is favorable for their national circumstances, but not necessarily one that prevents emissions from going uncounted or that limits the use of offsetting between LULUCF and other sectors. This absence of guidance could result in an even greater variety of accounting approaches in the next round of NDCs, further compounding the challenge of understanding how the NDCs will affect future global emission levels.

It is worth noting that most NDCs with a quantitative NDC target provide a single year target, rather than a budget over a period of time as was done under the KP. A single year target for the LULUCF sector can be meaningless for limiting warming if mitigation is subsequently reversed, for example, by resuming deforestation after 2030, or if carbon fluxes show high interannual variability. This is an issue for all sectors, but LULUCF mitigation is particularly vulnerable to reversal. Unfortunately, the PA rule-book contains no guidance on the use of single or multiyear targets, although this topic will be important in upcoming negotiations about the use of market mechanisms in achieving the NDCs.

Within the accounting guidance, three specific challenges for LULUCF accounting are singled out as requiring additional guidance: how to report and account emissions and removals from harvested wood products (HWPs), how to remove natural disturbances from LULUCF accounts, and how to address the effects of forest age-class structure that result from previous management practices. Very few of the current NDCs include such information, which contributes to ambiguity over how LULUCF emissions/removals are accounted and whether nonanthropogenic factors (such as extreme events or forest management legacy effects) have been removed. The NDC guidance will improve clarity in how these elements are addressed, but Parties are left to decide whether and how to address them.

HWPs contribute a significant proportion of LULUCF carbon fluxes: the total net emissions from HWPs in the tropics have been estimated at 0.7–2 GtCO2eq/year (Roman-Cuesta et al., 2016), and for some countries reported HWP carbon fluxes are larger than total net LULUCF emissions/removals (e.g., Australia, Canada; UNFCCC, 2018c). Very few NDCs specify how they will account for HWPs; most that do so state that they will use the production approach (see Text S19 and Table S12). The PA rule-book now requires Parties that include HWPs to explain which of the IPCC's approaches they are using, thereby improving transparency. However, the IPCC has explained that if a universal approach for HWPs is not used by all countries that report HWPs, some emissions may go uncounted and others may be double-counted (Ellison et al., 2011; IPCC, 2016, 2019). There is no agreed common approach in the NDC guidance, but the reporting rules do require all Parties that include HWPs in their greenhouse gas inventories to provide an estimate of HWP emissions/removals using the production approach, regardless of which IPCC accounting approach they apply; this allows the *ex post* tracking of progress to be done in a way that does not miss or double count any emissions. Nevertheless, countries may still use different rules to design and meet their NDCs, which could have a significant effect on accounted emissions fluxes. Consequently, the ex ante aggregation of NDCs may miss some HWP emissions, and some countries' balance sheets may look better than others' due to the approach used.

Similarly, the PA guidance requires Parties to indicate their methods for addressing natural disturbances and how these methods are consistent with IPCC guidance but does not specify which methods may be used. Currently, very few NDCs include such information: a handful of countries (Canada, Switzerland, Andorra, Australia, and New Zealand) plan to exclude emissions resulting from natural disturbances but do not disclose their methods. The KP rules (UNFCCC, 2011) only allow emissions from natural disturbances to be excluded if the subsequent removals from regrowth are also excluded and the land use does not subsequently change. The PA rule-book does not explicitly require such an approach to be taken, which could enable countries to use an approach for natural disturbances that benefits their accounts.

However, new guidelines for inventory compilers provided by the IPCC (IPCC, 2019) include generic guidance for those countries that choose to disaggregate their managed land emissions, into those considered to be anthropogenic and those considered to result from natural disturbances, to report how the disaggregation is performed. These guidelines, which have yet to be adopted for use under the PA, specify that it is good practice to include any removals associated with the natural disturbance in the disaggregation.

Parties should also describe any methods used for addressing emissions and removals caused by forest age-class structure, including how methods are consistent with IPCC guidance, but further guidance on which methods to use is lacking. The IPCC guidance is limited to providing methods for calculating and reporting carbon fluxes, and for applying accounting rules already agreed under the UNFCCC and KP. It does not offer guidance for which accounting rules to use and does not provide guidance for accounting rules that have not been previously agreed to. Most NDCs do not report clear, transparent methods for distinguishing between anthropogenic and nonanthropogenic sinks, and only a handful explicitly state that they will exclude natural sinks or will address the legacy effects of age structure (e.g., New Zealand). Some developing countries mention large sinks but do not include them in their emissions reduction targets (e.g., Zimbabwe) or do not provide data to support the existence of such large anthropogenic sinks (e.g., Central African Republic); others explicitly include natural forests (e.g., Lesotho). Explicitly excluding natural sinks from emissions accounting, and providing information on methods and data, would ensure greater comparability between NDCs and other data sets; the lack of clear guidance in the rule-book on how to exclude natural sinks may hinder such comparison.

A further limitation of the PA rule-set lies in its timeline. The new NDC guidance on information and accounting is mandatory for the second round of NDCs, and Parties are "strongly" encouraged to apply it to their first NDCs when these are updated by 2020 (UNFCCC, 2018b). This means that NDC guidance does not come into effect immediately. The majority of Parties have an NDC target for 2030 and are required to bring forward a second NDC by 2025; hence, additional information requirements for second NDCs may only apply to mitigation targets for 2035 or 2040, dependent on the countries' chosen time frames and pending further negotiation. Parties are encouraged to, and could, improve their NDCs by voluntarily applying these rules earlier.

In addition to the NDC guidance, the PA rule-book also includes a set of transparency rules describing what information Parties should include in their national reports to the UNFCCC (UNFCCC, 2018a). These include three elements that are relevant to ambiguity in the NDCs. First, there are rules for how Parties should track ex post progress against their NDCs. These rules can reduce ambiguity in LULUCF targets over time as Parties record progress in implementing their NDCs. However, until such records are in place (from 2024 onward), the transparency rules will not lessen ambiguity in ex ante tracking of future targets against the PA long-term goals. Second, there are requirements for Parties to provide projections of emissions/removals that indicate the impact of mitigation policies and measures. These projections are equivalent to those used in our analysis when NDCs do not include LULUCF targets. However, the rule-book explicitly states that such projections cannot be used to track progress against the NDCs. Third, Parties are to provide regular GHG inventories, which can be used to show how national emissions/removals reported by each country track over time. These reported data show total national emissions flows and hence differ from accounted emissions/removals that are caused by recent human activities. GHG inventories are important for understanding how NDC targets and accounted emissions relate to the GHG flows seen by the atmosphere.

4.3. Implications for Implementing the PA

The first Global Stocktake, in 2023, will track global progress in implementing the PA, including through ex post analysis of emissions levels up until 2023 and ex ante assessment of progress in providing NDCs that are in line with the PA's long-term goals. If the land components of NDCs are not made more understandable and less ambiguous before 2023, analysis for the Global Stocktake will face the same challenges and uncertainties that we outline in this study: Aggregations will have to make assumptions about how LULUCF contributes to economy-wide targets and rely on data sources that are not necessarily comparable or consistent with the NDC.

Under the new PA rules, most Parties will need to supplement the information in their current NDCs to include data sources and assumptions, and Parties with unclear or not-yet-confirmed accounting rules will need to choose and explain their accounting approaches. However, while these clarifications will be a step in the right direction, they will not be sufficient to provide clear and understandable LULUCF contributions that ensure ambitious and comprehensive emissions coverage. Our study suggests that the rule-book will lead to only a limited improvement in how LULUCF is incorporated into the NDCs. Therefore, Parties should seek to improve how their NDCs are communicated beyond the requirements of the PA rule-book, and the development of further guidance in the future to move Parties toward common accounting approaches would be beneficial.

To reduce ambiguity, NDCs should ideally include a separate and, if possible, quantified LULUCF target, supplemented with measures and policies for how it will be achieved. By separating the LULUCF mitigation components of NDCs from mitigation targets in other sectors, it will be easier to assess the level of mitigation anticipated in non-LULUCF sectors, while also incentivizing countries to develop their terrestrial sinks. In undertaking this assessment, we have identified opportunities for a number of countries to lower the ambiguity of their NDCs by providing additional information (see Tables 3 and S8). Many countries have the capacity to quantify their LULUCF and non-LULUCF contributions and simply need to communicate these more clearly in their NDC; most developed countries fall into this category. Other countries already include quantitative LULUCF information in their NDCs, but the LULUCF component is not fully quantifiable because certain information is still lacking. For example, the NDCs of Chile, India, and China all contain quantitative LULUCF targets but lack quantitative information on the reference level against which the LULUCF target is set, making it difficult to assess the anticipated LULUCF emissions/removals in 2030.

For those countries with limited capacities in accurately measuring, accounting and projecting LULUCF carbon fluxes, separate targets based on measures—e.g., zero net deforestation—may be more easily and accurately measured and verified. Certain measures-based targets may already be aligned with existing monitoring, reporting, and verification capacities, particularly among REDD+ countries, and can be clearly linked with local cobenefits for sustainable development, adaptation, or the protection of national public goods. Such motivations can stimulate higher levels of ambition (Keohane & Victor, 2016), especially where mitigation is not the primary driver for action, as is the case for countries that place measures-based LULUCF targets in the adaptation section of their NDCs (e.g., Ecuador and Mexico; Petersen & Varela, 2015). Additionally, targets for ending deforestation and enhancing restoration efforts can provide a clearer indication of how the land sector and its emissions/removals might evolve over time than single year mitigation targets can. Hence, they might be more readily compared with what is required in the land sector according to 1.5 °C emissions pathways.

In this study, we have focused on a source of uncertainty that can largely be reduced through improvements in information communication in the NDCs. However, reduction in other sources of uncertainty will require clear and accurate reporting by countries of LULUCF emissions/removals in their GHG inventories, as well as further work by the carbon flux research and observations communities. A significant challenge for the Global Stocktake will be the combination and comparison of different data sources to fill in data gaps, address data inconsistencies, and verify national data sets. The use of different definitions, conceptual frameworks, and methods currently hinders the comparison of national and global data sources (Grassi et al., 2018; Roman-Cuesta et al., 2016; Tubiello et al., 2015); for example, there is a discrepancy of ~4 GtCO2eq between historic LULUCF emissions estimates from national GHG inventories and the global models used to develop mitigation pathways (Grassi et al., 2018). Further collaborative research is needed to understand these differences and refine methods; in particular, agreement on what constitutes an anthropogenic sink and a natural disturbance will be important for transparently and accurately tracking progress towards the PA's goals of balancing anthropogenic emissions and removals and limiting warming to 1.5 °C.

5. Conclusions

In this paper, we categorize the NDCs according to how LULUCF mitigation is incorporated and quantify the effect of ambiguity in LULUCF treatment on our ability to aggregate the NDCs. Currently, LULUCF is included in 121 of the 167 NDCs, but there is substantial variation in how the land use sector is incorporated and many NDCs contain ambiguous LULUCF components. The majority of NDCs (56) simply include

LULUCF under their overarching mitigation target, with no clear information on how LULUCF mitigation will contribute toward the target. Forty-four NDCs include a distinct quantitative mitigation target for LULUCF, but only 11 of these targets are fully quantified.

According to our best estimates for emissions and removals in 2030 (which total 2.0 GtCO2eq/year for all countries), most emissions and most removals are covered by NDCs that lack sufficient information for full quantification. We estimate that ambiguity in how LULUCF activities contribute to mitigation targets creates an uncertainty range in LULUCF emissions/removals of 2.9 GtCO2eq/year in 2030. Three types of ambiguity make up this range: (i) ambiguity in which data sources are consistent with the NDC, when LULUCF projections are provided in other UNFCCC documents (16 NDCs); (ii) ambiguity caused by insufficient information in the NDC or elsewhere to understand the LULUCF contribution (12 NDCs); and (iii) ambiguity over how to calculate the contribution of LULUCF, where a separate LULUCF target is provided without the complete information necessary to quantify its effect (four NDCs). When ambiguous LULUCF contributions are integrated under a headline mitigation target, ambiguity in the share of LULUCF carbon fluxes can leak to other sectors; 23 NDCs with this type of LULUCF treatment contribute ~2 GtCO2eq of uncertainty. It is important to note that our uncertainty estimates are themselves uncertain, being based on a set of possible scenarios that are consistent with the NDCs. However, by estimating this previously unquantified form of uncertainty, we show that ambiguities render the tracking of anticipated progress substantially more challenging, both for land-based mitigation and for other sectors.

Achieving the goals of the PA, including net zero GHG emissions in the second half of the century, requires rapid emissions reductions across all sectors. Fossil fuels need to be phased out and deforestation halted within the next few decades. Our analysis demonstrates that the current NDCs do not provide sufficient clarity in their LULUCF contributions to ensure the swift, ambitious, and verifiable action demanded by the PA goals. The PA rule-book addresses some sources of ambiguity through its NDC guidance, but not as far as necessary to reduce uncertainties in ex ante tracking.

A more robust Global Stocktake would benefit from countries taking a step beyond these formal requirements to provide more information on LULUCF contributions in their updated NDCs. Ambiguity could be reduced through simple clarifications over, for example, LULUCF data sources, and reference and target levels; a finding shared by Rogelj et al. (2017) for uncertainties in non-LULUCF sectors. Parties should ideally seek to provide a separate, quantifiable emissions target for LULUCF activities, as this would prevent any leakage of uncertainties to other sectors. The use of measures-based targets to complement specified emissions reduction targets could further increase the clarity, transparency, and stringency of LULUCF mitigation.

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